# Chapter 7

# Thorax: Sternum and Ribs

In primitive, air-breathing fishes, breathing was accomplished by swallowing movements in which air was gulped into the lungs. Early reptiles improved on this system when they evolved a means to respire via the musculoskeletal mechanics of the thoracic skeleton. This was made possible as the thoracic ribs extended ventrally from the vertebral column to reach the sternum. The sternum formed a kind of ventral bony column that fused into a bony bar and anchored the distal ends of the ribs. Further soft tissue specializations led to more sophisticated breathing functions.

The skeleton of the human thorax, or chest, is like a basket or cage composed of cartilage and bone. It is attached dorsally to the vertebral column. This structure encloses and protects the principal organs of circulation and respiration, the heart and lungs, and is the base to which the upper limbs are attached. The major bones forming the thorax are the sternum and the 12 ribs on each side. The upper seven ribs on each side connect, via cartilage, directly with the sternum and are sometimes called "true," or "sternal," ribs. Ribs 8–10 attach to the sternum indirectly, also via cartilage, and are sometimes called "false," or "asternal," ribs. The last two ribs ("floating" ribs) have short cartilaginous ends that lie free in the sides of the body wall.

## 7.1 Sternum (Figures 7.1–7.2)

### 7.1.1 Anatomy

The sternum, or breastbone, functions at its upper end to connect the shoulder girdle (clavicle and scapula) to the thorax. In addition, it anchors the anterior ends of paired ribs 1–7 via cartilage. The bone is composed of three main parts in adulthood but develops from six segments (**sternebrae**). The segment joints may all fuse in adulthood, but their location is indicated by costal notches along each side of the sternum.

a. The **manubrium** is the most massive, thickest, and squarest of three main sternal elements. It is the superiormost element of the sternum and is the widest part of this bone.
b. **Clavicular notches** occupy the superior corners of the sternum. It is here that the manubrium articulates with the right and left clavicles.
c. The **jugular (or suprasternal) notch** is the midline notch on the superior border of the manubrium.

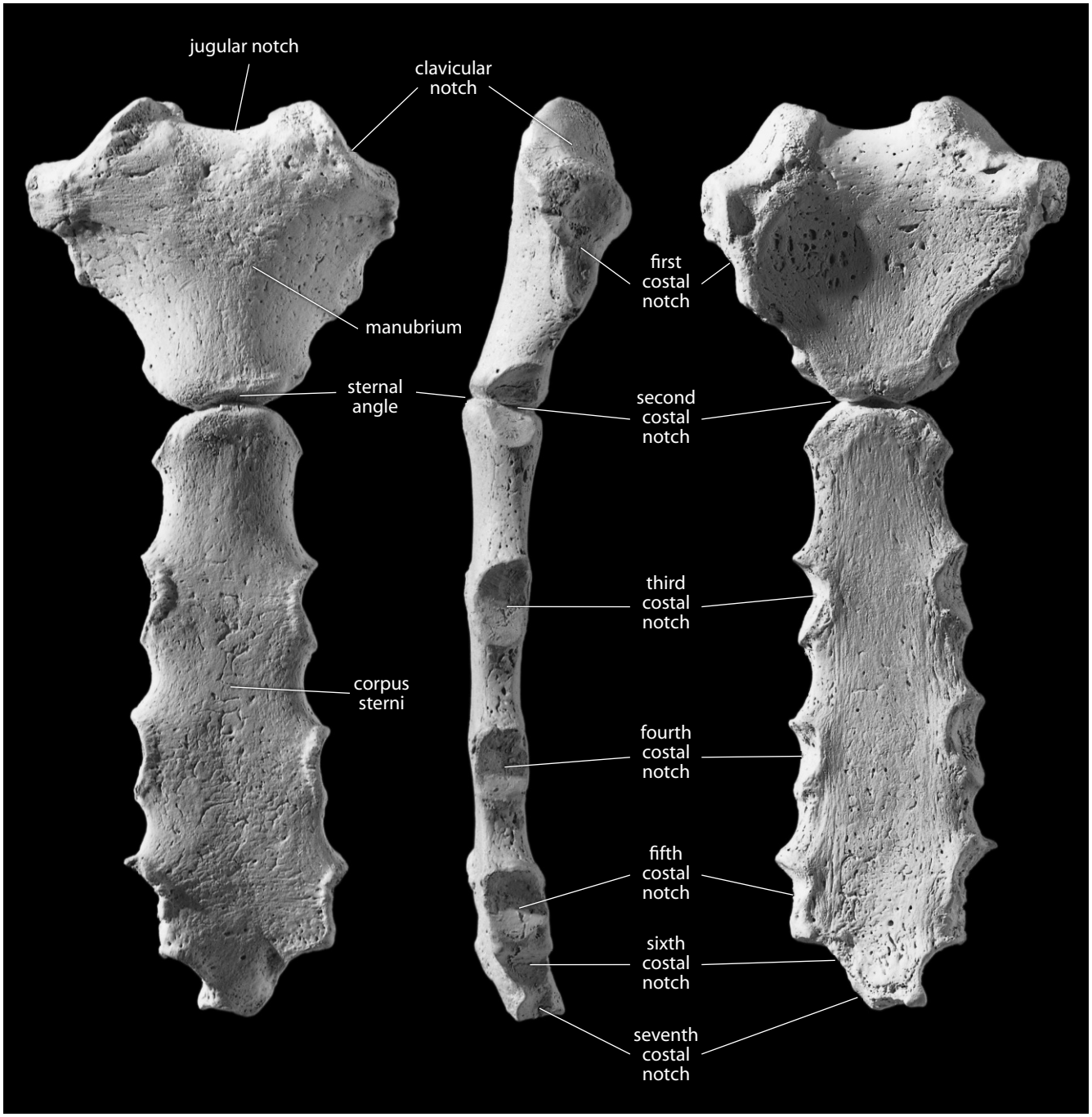


Figure 7.1 **Sternum.** *Left:* anterior view; *center:* left lateral view; *right:* posterior view. The xiphoid process on this sternum had not ossified and is not shown. Superior is up. Natural size.

d. **Costal notches** occupy both sides of the manubrium inferior to the clavicular notches. These notches represent articulations with the costal cartilages of the first ribs. The manubrium shares articulation for the second ribs with the corpus sterni.

e. The **corpus sterni** (or **mesosternum**) is the central part, the body, or blade, of the sternum. It is formed during ontogeny from the fusion of sternal segments (sternebrae) 2–5. The corpus sterni may fuse, partially fuse, or remain unfused with the manubrium in adulthood.

f. The **sternal angle** (or **manubriosternal joint**) is the angle formed (viewed laterally) between the fused manubrium and the corpus sterni.

g. The **costal notches** along either side of the corpus sterni are for articulation with the costal cartilages of ribs 2–7.

h. **Lines of fusion** are often apparent between the sternebrae. These lines pass horizontally through the right and left costal notches for ribs 3–5.

i. The **xiphoid process** is the variably ossified inferior tip of the sternum. It often fuses with the corpus sterni in older adults. It shares the seventh costal notch with the body. This process can be partially ossified and may ossify into bizarre asymmetrical shapes with odd perforations. In short, the xiphoid is a highly variable element. The xiphoid process of the individual chosen to illustrate this text, for example, was not ossified at the time of death.

### 7.1.2 Growth

The four superior centers of ossification (manubrium and corpus sterni segments 2–4) appear in fetal life. The timing of fusion between sternal segments is often irregular, but fusion between the lower two centers in the corpus sterni (segments 4 and 5) occurs soon after puberty. Fusion occurs between segments 2, 3, and 4 by early adulthood. As mentioned earlier, the manubrium and corpus sterni sometimes fail to unite, even in adulthood.

### 7.1.3 Possible Confusion

Fragments of the sternum might be mistaken for fragments of pelvis or immature vertebrae.

- The costal and clavicular notches, and the lines of fusion between sternal segments, should be sufficient to ensure correct identification.
- The sternum is a bone with very low density. Its cortex is paper-thin, perforated by numerous microforamina. This makes even fragmentary sterna easy to sort from other elements, such as the pelvis.
- Infant sternebrae are often confused with vertebral centra. Infant centra have rougher, less mature (*i.e.,* more billowed, granular) cortical surfaces.

### 7.1.4 Siding

- Fragments of manubrium and corpus sterni can be sided by noting that the anterior surface of this bone is rougher and more convex than the smooth, gently concave posterior surface.
- The lines of fusion pass horizontally, and the mediolaterally widest point on the corpus sterni is at the third segment inferior to the manubrium.

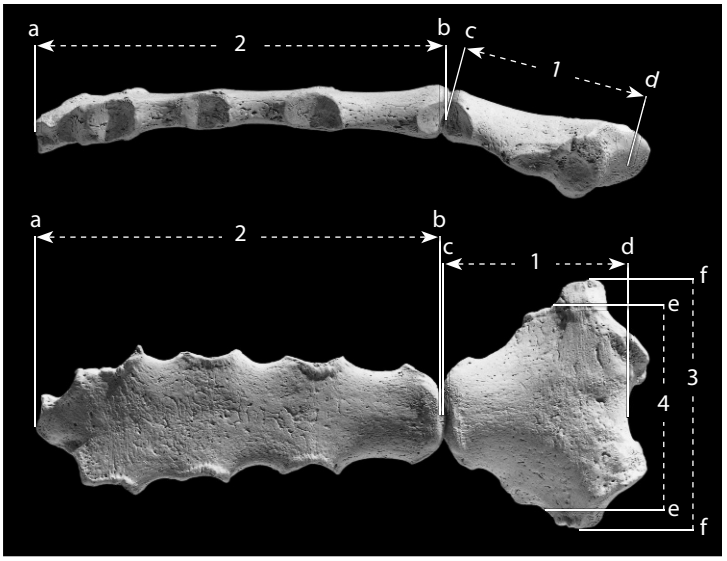


Figure 7.2 **Sternal measurements.** One-half natural size.
*Locations:* a) center of inferior articular facet of corpus sterni; b) center of superior articular facet of corpus sterni; c) center of inferior articular facet of manubrium; d) inferiormost point of jugular notch; e) centerpoint of first costal notch; f) lateralmost point on manubrium.
*Measurements:* 1) manubrial length; 2) length of the corpus sterni; 3) maximum manubrial breadth; 4) manubrial breadth.

## 7.1.5 Sternal Measurements (Figure 7.2)

Measurements of the sternum are infrequently taken or used in formulas, but are indicators of sexual dimorphism and have been used in formulaic determinations of sex.

1. **Manubrial length** (Martin, 1928: 1004, #2): Place the tip of the stationary jaw of the sliding caliper into the deepest (most inferior) point of the jugular notch and measure the distance to the inferiormost point on the inferior articular facet of the manubrium.
2. **Length of the corpus sterni** (Martin, 1928: 1004, #3): With a sliding caliper, measure the superoinferior distance from the center of the superior (manubrial) articular facet to the center of the inferior (xiphoid) articular facet.
3. **Maximum manubrial breadth** (Martin, 1928: 1004, #4): With a sliding caliper, measure the greatest breadth of the manubrium.
4. **Manubrial breadth** (Bass, 1995): With a sliding caliper, measure the distance between the centers of the first costal notches.

## 7.1.6 Sternal Nonmetric Traits

- The **sternal foramen** perforates the sternal body in about 7% of adult corpora sternorum (Cooper et al., 1988). Sometimes referred to as a 'perforated sternum,' the sternal foramen results from an incomplete midline fusion of the lower 2–3 sternebrae, which commonly ossify from bilateral centers, rather than from a single midline center as with the superior sternebrae.
- The fusion (synostosis) of the manubriosternal joint (between manubrium and corpus sterni) occurs in about 20% of adults (Yekeler et al., 2006). Fusion can be of two types: 1) matrical synostosis, due to a developmental anomaly resulting in an absence of a fibrocartilaginous barrier between elements, or 2) sclerotic synostosis, due to age-related degeneration of the fibrocartilaginous pad in the joint. The latter type is predominantly found in older females (Scheuer and Black, 2000).
- In about 30% of adults, the xiphoid process has at least one foramen (Yekeler et al., 2006).

## 7.2 Ribs (Figures 7.3–7.6)

### 7.2.1 Anatomy

There are usually 12 ribs on each side of the thorax, for a total of 24 in the adult male and female human body. The number of ribs is variable; there may be 11 or 13 ribs on a side, with supernumerary ribs in either the cervical or lumbar segment (Black and Scheuer, 1997). The upper seven ribs (numbers 1–7) articulate directly with the sides of the sternum via the costal cartilages and are called sternal or "**true ribs**." Ribs 8, 9, and 10 are interconnected medially by common cartilages that attach to the sternum. Because they lack a direct sternal connection, these ribs are called asternal or "**false ribs**." The last two ribs, 11 and 12, have free-floating distal ends, and are referred to as "**floating ribs**." All ribs articulate via their proximal ends with thoracic vertebrae. The ribs usually increase in length from rib 1 to rib 7, and decrease from rib 7 to rib 12. Concern with the use of the sternal rib end to estimate adult age at death (Chapter 19) has led several investigators to refine methods of siding and sequencing human ribs (Mann, 1993; Hoppa and Saunders, 1998). These apply to ribs known to be from a single individual.

a. The **head** of a rib is the swollen proximal part of the rib. It bears two articular surfaces (**demifacets**) for contact with the bodies of successive thoracic vertebrae. The first rib and ribs 10–12 are unifaceted.
b. The **crest of the rib head** marks the separation between the two demifacets.
c. The **neck** of a rib is the short segment between the head and the rib's articulation with the transverse process of the thoracic vertebra.
d. The **crest of the rib neck** runs between the head and tubercle.
e. The **tubercle** is located on the posteroinferior corner of each rib. It articulates with the transverse process of the thoracic vertebra, presenting a medial **articular facet** for articulation with the transverse process of the thoracic vertebra, and a nonarticular portion for ligamentous attachment.
f. The **angle** (or **costal angle**) is the sharp curve in the bone lateral to the tubercle. It is marked by a prominent line on the external surface of the shaft immediately distal (lateral) to the tubercle. This line marks the attachment of the deep muscles of the back. It also marks the shift from the caudally facing external rib surface to the more cranially oriented external surface. The tubercle-to-angle distance increases from rib 4 to rib 11.
g. The **shaft** of a rib is the curved, tapering segment between the tubercle and the rib's distal (ventral, anterior) end. Shafts of ribs 3–6 are thicker and rounded in section compared to those of ribs 7–12.
h. The **costal groove** of a rib is the groove along the medial side of the inferior edge of the rib shaft. In life this groove houses an *intercostal artery*, *vein*, and *nerve*. It is most prominent on ribs 5–7.
i. The **sternal end** of a rib is the anterior (ventral) end of the shaft. This end is a roughened, porous, cupped oval surface for the attachment of cartilage. Its surface changes substantially with increasing age. The sternal ends of ribs 11 and 12 taper to a point. The sternal ends of ribs 1–10 end in a **pit** where they meet the costal cartilage.
j. The **cranial** (or **upper**) **edge** of most ribs is blunt, smooth, and convex.
k. The **caudal** (or **lower**) **edge** of most ribs is sharp, with a costal groove on the medial surface. This groove gives a concave appearance to the surface of the rib that faces the body cavity.

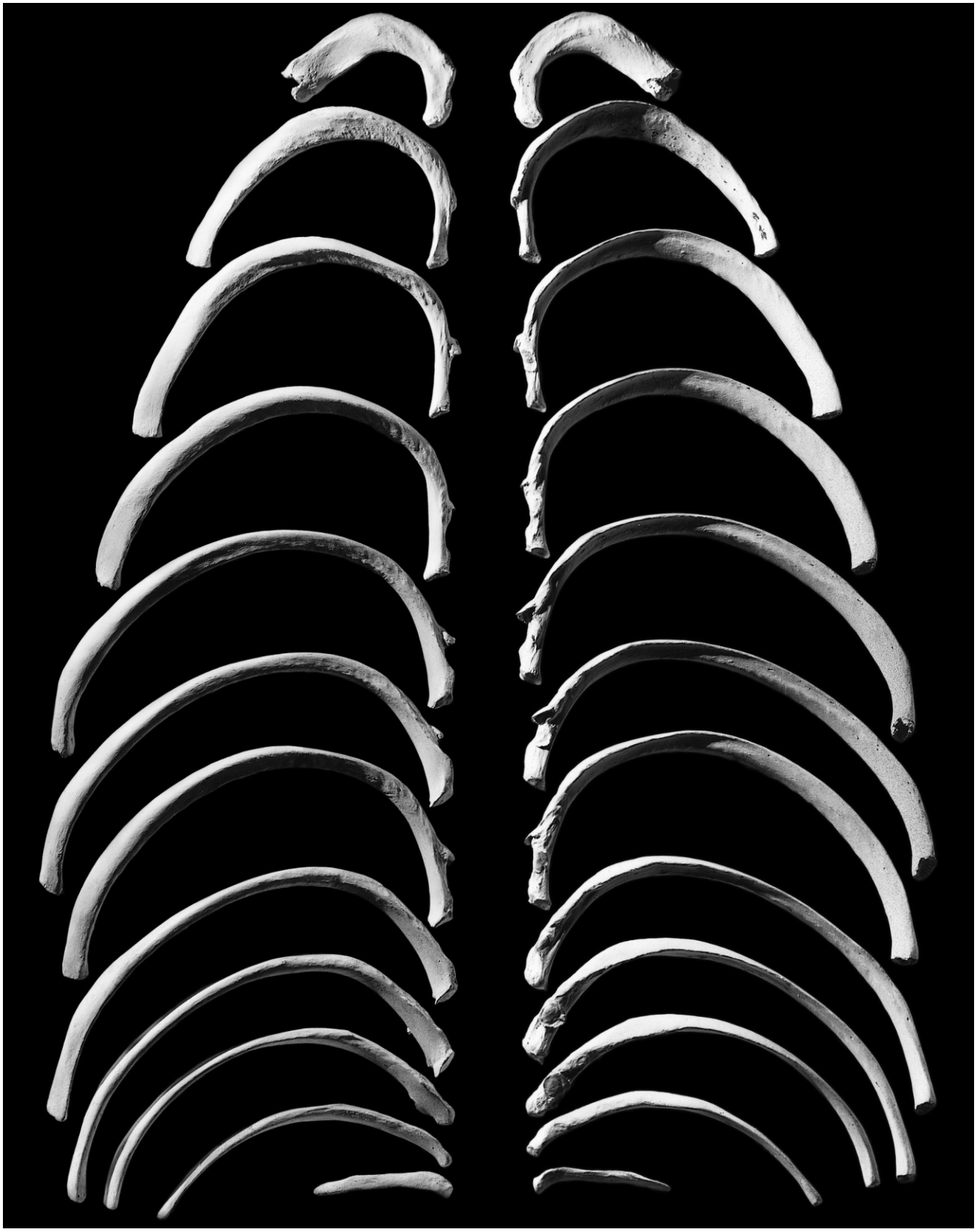

Figure 7.3 **Right ribs.** *Left:* superior view; *right:* inferior view. One-third natural size.

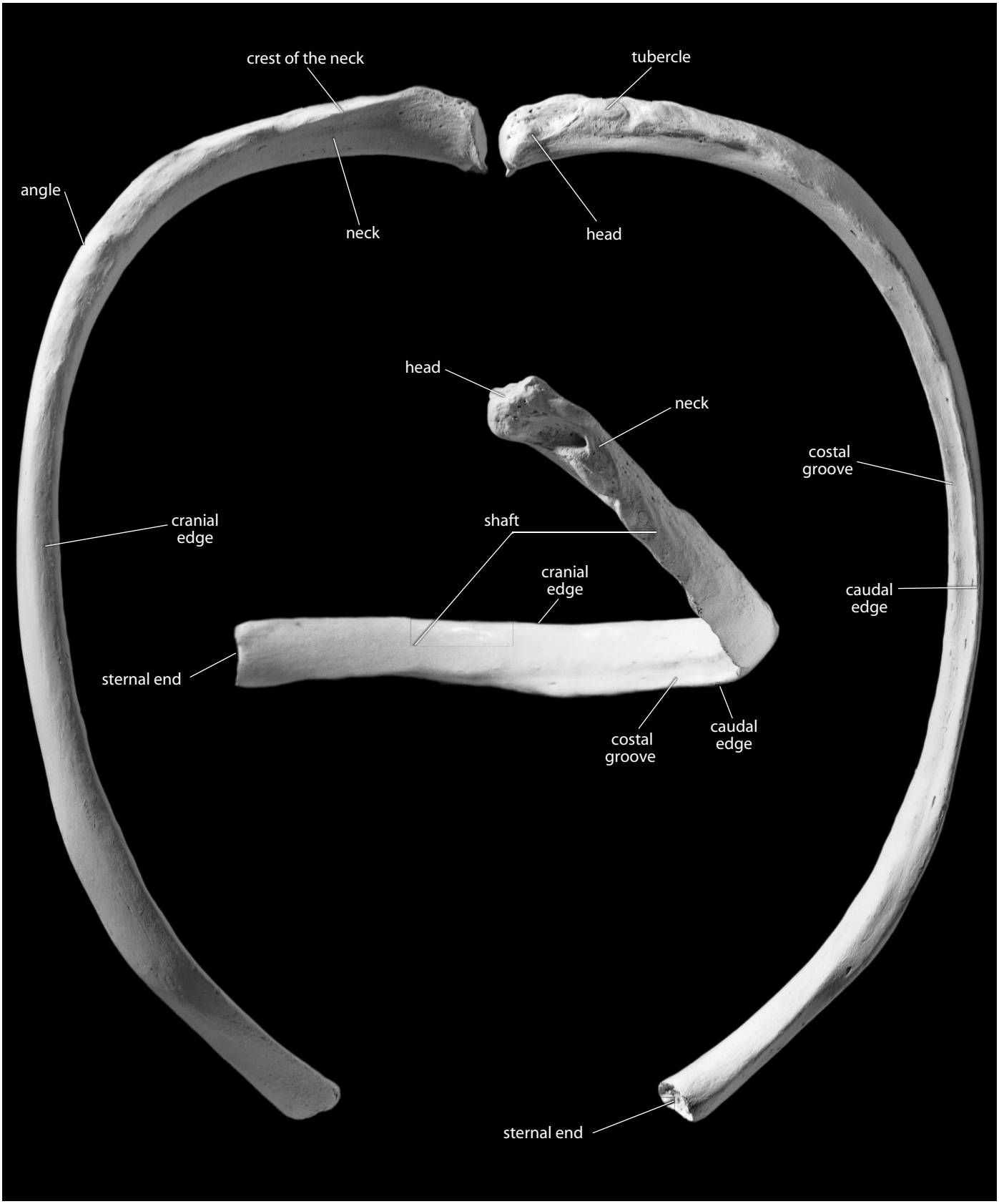


Figure 7.4 **Right eighth rib, a "typical" rib.** *Left:* superior view; *right:* inferior view; *inset:* posteroinferior view. Natural size.

### 7.2.2 Special Ribs (Figure 7.5)

- The first rib is the most unusual and therefore most easily diagnosed rib. It is a broad, superoinferiorly flattened, short, tightly curved bone with only one articular facet on its small rounded head. Its superior (cranial) surface is roughened by muscle attachments. This surface also bears two shallow grooves: the anterior one for the *subclavian vein* and the other for the *subclavian artery* and *inferior trunk of the brachial plexus* (medial) (Figure 7.5). The ridge between these grooves is prolonged ventrally into the scalene tubercle for the attachment of the *anterior scalene muscle*. There is no true inferior costal groove.
- The second rib is intermediate between the unusual first rib and the more typical ribs 3–9. It has a large tuberosity for the *serratus anterior muscle* near the external (cranial), midshaft position (Figure 7.5).
- The tenth rib is like ribs 3–9 but usually has only a single articular facet on the head.
- The eleventh rib has a single articular facet on the head and lacks a tubercle. Its sternal end is narrow and often pointed. Its shaft has a slight angle and a shallow costal groove.
- The twelfth rib is shorter than the eleventh and may even be shorter than the first. This rib is similar to the eleventh in morphology and also lacks the angle and the costal groove.

### 7.2.3 Growth

Ribs, except for the eleventh and twelfth, ossify from four centers. Epiphyses for the head and for the articular and nonarticular parts of the tubercle appear in the teens. They fuse to the rib body in early adulthood.

### 7.2.4 Possible Confusion

- A fragmentary first rib might be mistaken for an inferior ramus of the os coxae. The cortex of the rib, however, is not as thick, the surface is more irregular, and the cross section is much thinner than in the os coxae.
- Proximal ends of other ribs, when broken into short segments, could be mistaken for metatarsal or metacarpal shafts. However, the cross section of a rib is more irregular, with one sharp edge. Usually the tubercle, head, or part of the costal groove is enough to diagnose a broken specimen as a rib.
- The head and neck of the first rib are flatter and smaller, respectively, than a transverse process from a thoracic vertebra.
- The head of a rib might be confused with a broken infant ulna, but attention to bone maturity can aid in the diagnosis of these parts.

### 7.2.5 Siding

- For the first rib, the head and neck point inferiorly, and the superior surface bears grooves when in correct anatomical position.
- For all other ribs, the heads point toward the midline, and the tubercles are inferior.
- The cranial edge is thicker and blunter than the grooved, sharp inferior edge.
- The inner surface of the twelfth rib faces superiorly.

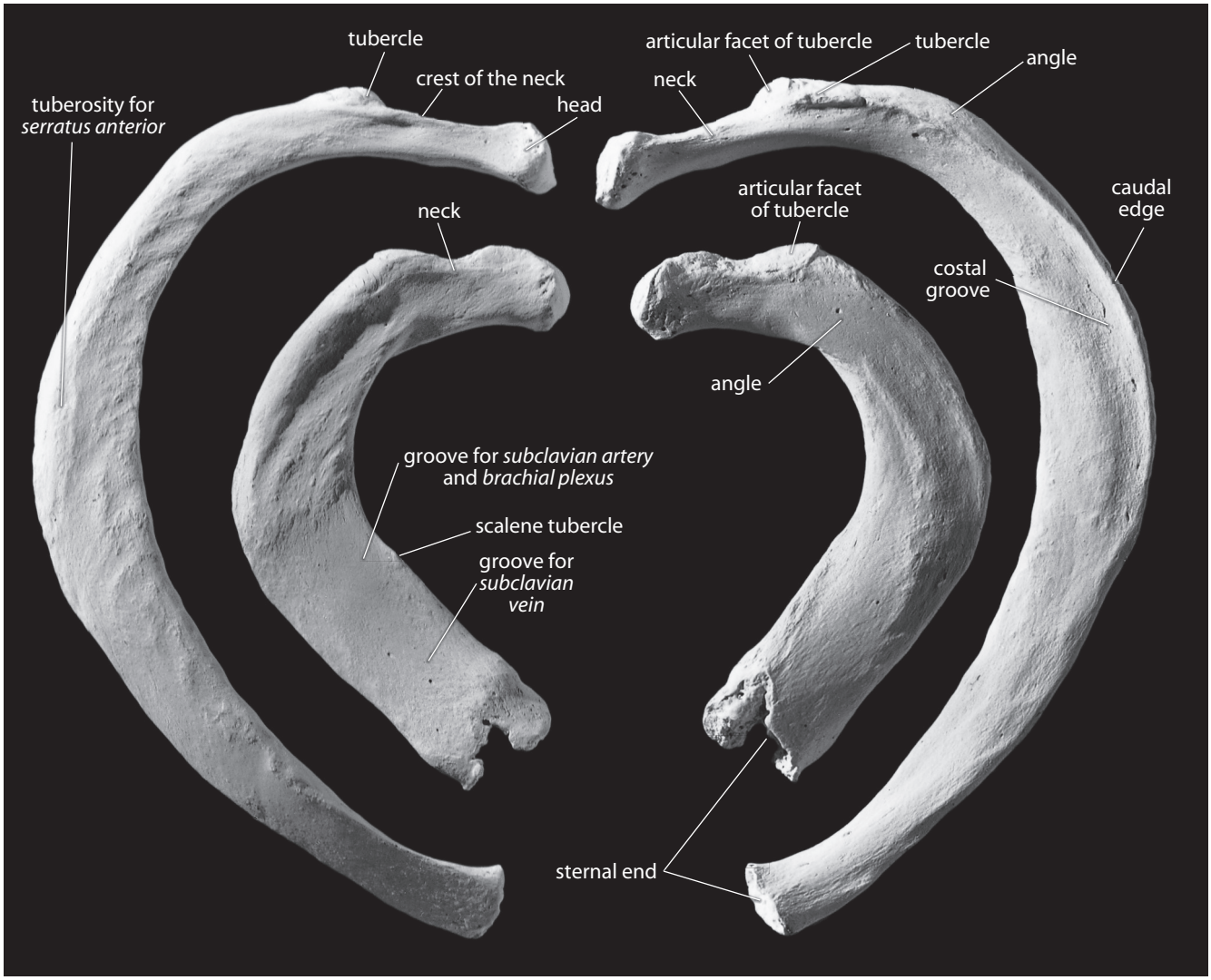


Figure 7.5 **Right first and second ribs.** *Left:* superior view; *right:* inferior view. Natural size.

## 7.2.6 Costal Measurements (Figure 7.6)

Measurements of the ribs are infrequently taken, but these values have been used in biomechanical formulas related to respiration, climatic adaptation, and trunk shape, as well as being useful in determining lateral asymmetry (helpful in diagnosing pathologies such as idiopathic scoliosis).

1. **Total rib length** (Martin, 1928: 1005, #4): Place the tip of the stationary end of the sliding caliper on the center of the head and measure the distance to the centerpoint of the sternal end.
2. **External arc of rib** (Martin, 1928: 1005, #3): With a flexible cloth measuring tape, measure the distance along the greater curvature of the rib (the external surface) from the center of the head to the centerpoint of the sternal end.

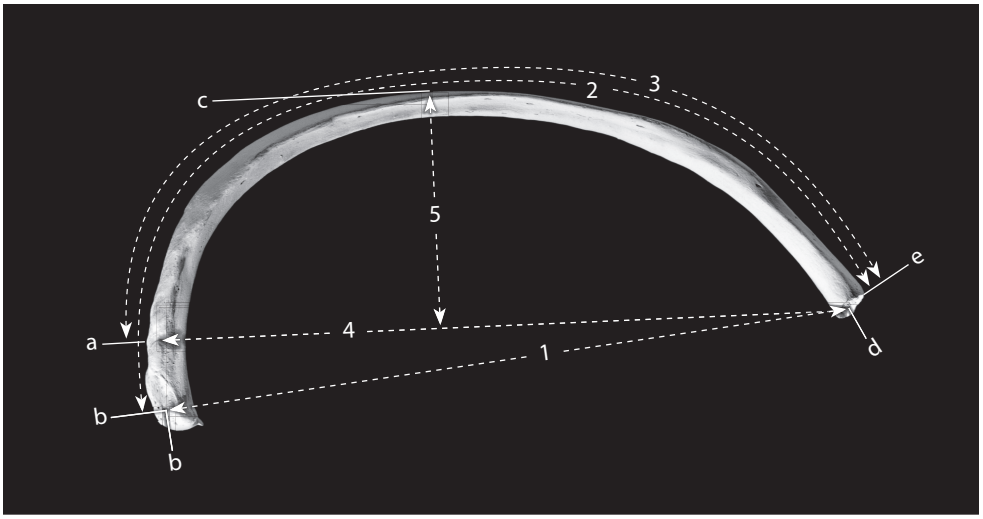


Figure 7.6 **Costal measurements.** One-half natural size.

*Locations:* a) distalmost point on tubercular articular facet; b) middle of the rib head; c) lateralmost point on shaft (point orthogonally farthest from '4'); d) center of sternal end; e) rim of sternal end.

*Measurements:* 1) total rib length; 2) external arc of rib; 3) tuberculoventral arc; 4) tuberculoventral chord; 5) tuberculoventral subtense.

3. **Tuberculoventral arc** (Gómez-Olivencia, et al., 2009: 78; after McCown and Keith, 1939: figure 75): With a flexible cloth measuring tape, measure the distance along the greater curvature of the rib from the distalmost point of the tubercular articular surface to the sternal end of the rib (for ribs 1–9 only).
4. **Tuberculoventral chord** (Franciscus and Churchill, 2002: 311–312; after McCown and Keith, 1939: figure 75): With a sliding caliper, measure the minimum distance from the distalmost point of the tubercular articular surface to the ventralmost point on the sternal end of the rib (for ribs 1–9 only).
5. **Tuberculoventral subtense** (Franciscus and Churchill, 2002: 312; after McCown and Keith, 1939: figure 75): Using a coordinate caliper (or two sliding calipers), measure the perpendicular distance from the tuberculoventral chord to the lateralmost point on the shaft.
6. **Sternal end maximum diameter** (Arensburg, 1991): Using a sliding caliper, measure the maximum diameter of the sternal end of the rib (i.e., along the major axis).
7. **Sternal end minimum diameter** (Arensburg, 1991): Using a sliding caliper, measure the minimum diameter of the sternal end of the rib.

## 7.2.7 Costal Nonmetric Traits

- **Cervical and lumbar ribs:** Supernumerary ribs are occasionally found articulating with the seventh cervical vertebra (0.2% of individuals: Galis, 1999) or the first lumbar vertebra (8.8% of individuals: Lanier, 1944).
- **Bifid ribs:** The sternal end of any true rib, but primarily ribs 3–6, may be congenitally

split (Barnes, 1994). Bifid ribs include ribs that are split into sternal ends of either equal or different lengths, ribs that have spurs indicating incomplete bifurcation, ribs that split and then rejoin (leaving a fenestration), as well as ribs that are abnormally wide (and often bilobate in cross section), or ribs that flare at the sternal end into a 'terminal club.'

## 7.3 Functional Aspects of the Thoracic Skeleton

This introduction to the vertebrae, ribs, and sternum treats these elements individually. It is also important to note the functional interconnections between the elements and the dynamic, coordinated role that they play in the living human. The lungs, which function to transmit gases in and out of the bloodstream, are protected by the ribs, sternum, and vertebrae. However, these skeletal elements do more than just protect the lungs, heart, and great vessels—they provide attachment for respiratory muscles and for muscles that move the forelimbs. Inhalation, bringing oxygen-rich air into the lungs, requires action of the thoracic musculoskeletal system. Expiration is usually more passive, except during heavy breathing.

The inhalation of several liters of air is accomplished by increasing the volume of the thorax. During inhalation, the diaphragm is depressed and the ribs, particularly ribs 2–6, rotate about an axis through their heads as their sternal ends and the sternum itself are lifted superiorly and slightly anteriorly. In addition, the lower ribs move into more horizontal positions, widening the transverse diameter of the thorax. These actions increase the volume of the thorax, and atmospheric pressure then forces air into the elastic lungs contained within.

There are several muscles involved in inhalation. The ribs are elevated by the *scaleni muscles,* the diaphragm (attached to the xiphoid process, the lower four ribs, and the bodies and arches of lumbar vertebrae 1–2), and the external intercostal muscles (which attach between adjacent ribs). When forceful exhalation is called for, the internal intercostal muscles, which are oriented at nearly right angles to the external ones, depress the ribs. This is assisted by contraction of abdominal muscles to decrease the volume of the thorax and thus expel air.